Significant Research Outcomes

U.S.-China Clean Energy Research Center (CERC)
Building Energy Efficiency (BEE)

December 2016

CERC Phase 1 (2011-2015)[1]

1. Building Design

- ***1.1 Modeling Human Behavior in Energy Simulation Tools:*** The human dimension, with seamless integration of technologies, is critical to achieving low- or zero-net-energy buildings in the United States and China. CERC-BEE researchers from Lawrence Berkeley National Laboratory (LBNL) in the United States, and Tsinghua University and the Ministry of Housing and Urban-Rural Development (MOHURD) in China, in collaboration with industry partners Bentley Systems, C3 Energy, Swire Properties, and Vanke, studied human behavior in building energy systems. Researchers developed new methods and simulation tools to characterize human behavior and quantify its relative impact on building energy performance. The project developed new data, methods, tools, and case studies to gain a deeper understanding of energy use in buildings and the driving factors, and integrate human behavior insights, through data analytics, modeling and simulation, in building design and operations to reduce energy use and greenhouse gas (GHG) emissions. Three occupant behavior modeling tools were developed and released: (1) the Occupancy Simulator to simulate occupant presence and movement in buildings and generate occupant schedules for building performance simulation, (2) obXML, an ontology and XML schema to standardize representation and exchange of occupant behavior models for building performance simulation, and (3) obFMU, a functional mockup unit of occupant behavior models for co-simulation. Twenty peer-reviewed journal articles were published. The project established intellectual leadership in occupant behavior research, which enables LBNL and Tsinghua University to jointly establish and lead the international collaboration project under the International Energy Agency (IEA) Energy in Buildings and Communities (EBC) Program Annex

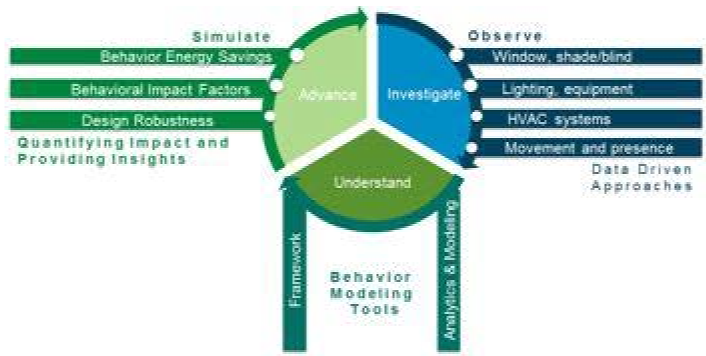

Figure 1: A Framework for Modeling Human Behavior in Buildings

[1] For additional information about each project, including partners, research objectives, outcomes, collaboration, and other details, refer to the Project Fact Sheets: http://www.us-china-cerc.org/pdfs/BEE_Factsheets_Phase_1_Final.pdf

66 with more than 100 researchers from 22 countries. The joint U.S.-China research team also formed and leads the new ASHRAE Multidisciplinary Task Group on occupant behavior in buildings. The project also made significant contributions to the ISO Standard 12655, the China building energy design standard GB 50189-2015, and the new building energy consumption standard GB/T51161-2016.

- ***1.2 Integrated Design—Developing Protocols and Design Tools for Very Low Energy Buildings***: CERC-BEE researchers from LBNL (U.S.), Tsinghua University (China), and Bentley Systems (U.S.) studied actual energy performance of 51 high performance buildings in the United States, China, other regions of Asia, and Europe, and determined that: (1) buildings with high performance ratings did not necessarily consume less energy; (2) energy-use intensities of these buildings vary by a factor of more than ten; (3) there is no a single factor determining energy use in buildings; (4) simply adding more building technologies may not lead to low energy use; and (5) integrated design, operations, and human behavior in buildings is the key to achieving superior energy performance. Based on these results, CERC researchers provided guidance to improve the design of very low energy use demonstration buildings in China, which can improve energy efficiency in China and facilitate acceptance of U.S. products in global buildings markets.

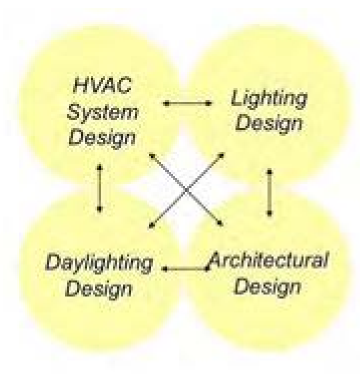

Figure 2: A Framework for Integrated Design

2. Building Envelope

- ***2.1 Windows—Demonstrating Advanced Switchable Electrochromic Windows, Dimmable Lighting, and Low-energy Cooling Strategies that Result in Cost-effective Net-zero Building Energy Performance when Integrated with Building Integrated Photovoltaic (PV):*** Advanced window and shading technologies can cut electricity demand for lighting, and heating, ventilation, and air-conditioning (HVAC) – saving energy and reducing emissions. CERC-BEE researchers from LBNL, Tongji University, and Chongqing University, in partnership with Saint-Gobain and Sage Electrochromics demonstrated through simulations and field tests that advanced switchable electrochromic windows or operable exterior shading could reduce perimeter zone annual energy use by 50-80%. When integrated with model predictive controls, electrochromic windows, dimmable lighting, and low-energy cooling systems controlled in conjunction with


Figure 3: Installation of Sage Electrochromic Windows in the LBNL Advanced Windows Testbed

onsite photovoltaics and energy storage were shown (Figure 3) to lower peak electricity demand from the utility grid to near-zero during the daytime and to reduce total perimeter zone electricity use by 63% compared to conventional heuristic controls. Demonstration of U.S. products in the rapidly expanding buildings market in China can enable further marketing opportunities for U.S. businesses. Separately, MOHURD agreed to adopt ISO 15099, which specifies procedures for determining thermal and optical transmission properties of windows, and a Chinese version of LBNL's WINDOW 6 software was released.

- ***2.2a Air Barriers—Developing Award-Winning Sprayable Liquid Flashing***: Dow Chemical (U.S.) and Oak Ridge National Laboratory (ORNL) developed a sprayable liquid flashing technology – LIQUIDARMOR-CM and RS – that contributes to increasing the air tightness of commercial and residential buildings in the United States and China. The product was demonstrated at several U.S. buildings and at the China Academy of Building Research (CABR) building in Beijing. LIQUIDARMOR is more cost-effective, as a result of a 75% shorter installation time (when compared to tape), and improved workmanship, due to ease of installation. LIQUIDARMOR was selected as an R&D100 finalist in 2015, won the 2016 Gold Edison Award for Building Construction & Lighting Innovations, and was awarded a patent (US 8,641,846 B2). Research will continue under CERC's phase 2 to tailor the formulation of LIQUIDARMOR to different environmental settings. In an effort to increase knowledge among building owners and designers about the importance of reducing air leakage through envelopes, ORNL, - National Institute of Standards and Technology, and Air Barrier Association of America jointly developed a free online calculator that estimates energy savings from improvements in airtightness in several cities in the U.S., China, and Canada.

Figure 4: DOW's LIQUIDARMOR Sprayable Liquid Flashing Technology

- ***2.2b Air Barriers—Developing Primer-Less Self-Adhered Membranes That Require Half the Installation Time:*** 3M (U.S.) and ORNL developed a new self-adhered membrane that is easier and faster to install than the prevailing asphalt-based membranes. The new technology, created under CERC-BEE and introduced in U.S. markets under the name "3M 3015", is an air, water, and vapor barrier membrane that has excellent adherence to common building materials without the use of a primer. As a result, 3M 3015 allows for up to 2 times faster installation than membranes that require priming. Another advantage that

Figure 5: 3M's Primer-Less Self-Adhered Membranes

3M 3015 has over competing products is that it is ideal for winter construction because it can be installed at temperatures that are as low as 0°F. Research will continue under CERC's second phase to evaluate the performance of the newly-developed vapor permeable, primer-less self-adhered membrane 3M 3015VP. Development of commercial products, such as LIQUIDARMOR and 3M 3015, was largely made possible due to the unique combination of skills, expertise, and market access that CERC provides. CERC facilitated and leveraged the complementary skills and resources of U.S. and Chinese partners, and both industry and research partners benefited: industry gained greater access to top researchers and laboratory equipment and to new markets in both countries, and the national laboratories drew from industry expertise in the technology-to-market process and received access to industrial facilities for demonstrations.

- ***2.3 Cool Roofs—High-performance, Long-life, Energy-saving Cool Roof Materials*.** Sunlight absorbed by dark roofs heats our buildings and cities in summer. This increases need for air conditioning, strains the electric grid, aggravates smog, and endangers the health of the infirm and elderly, especially during heat waves. American-made solar-reflective "cool" roofing products are widely used in U.S. cities to save energy, avoid brownouts and blackouts, improve air quality, and reduce risk of sickness and death on hot summer days. However, due to the lack of scientific analysis, building energy standard incentives, and a roof product rating system in China's buildings market, the marketability of U.S. cool roof technologies has been limited. CERC-BEE's researchers and industry partners collaborated to explore opportunities for cool roof technologies in China. This CERC-BEE effort is facilitating the development of a robust export market for U.S. cool roof technology. A large team of U.S. and Chinese researchers, including LBNL, ORNL, Dow Chemical, and partners from over 10 Chinese universities and building research institutes, investigated how to best adapt cool roof technology to Chinese climates, urban design, and building practices. Building simulations and real-building experiments showed that cool roofs conserve energy, save money, and reduce emissions in all hot-summer Chinese climates. Meteorological simulation of the hot and populous Chinese city of Guangzhou found that the widespread adoption of cool roofs could significantly reduce summer afternoon air temperature, especially during heat waves. This science was used to promote the inclusion of cool-roof credits in Chinese building energy standards and green building rating programs. Multi-year trials in nine Chinese cities are tracking the ability of light-colored roofs to stay clean and reflective in polluted climates. The results from the trials are being used to adapt the Cool Roof Time Machine, an ASTM-approved laboratory method

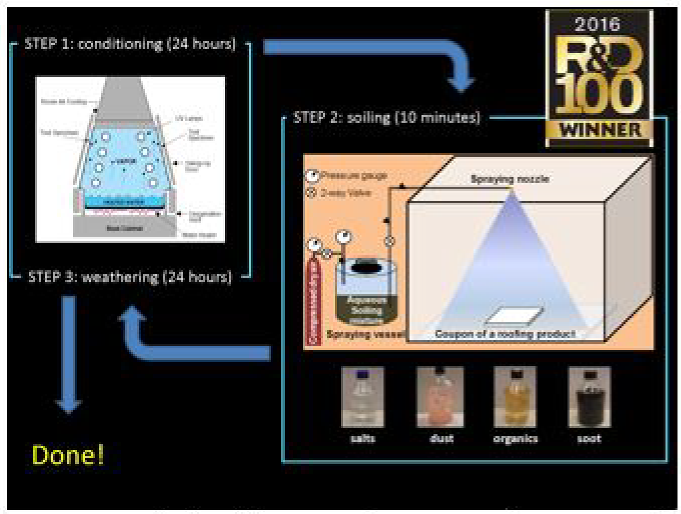

Figure 6: Berkeley Lab's 2016 R&D 100 Award Winning Cool Roof Time Machine

developed by LBNL, for application to the Chinese market. This Cool Roof Time Machine determines, in only three days, the long-term performance of cool roofing products. ORNL and Dow Chemical created, and LBNL tested with the Cool Roof Time Machine, prototypes of a "superhydrophobic" (highly water repellent) long-life white roof coating designed to stay clean in polluted Chinese and U.S. cities. In February 2016, a Chinese industrial standard added credits that incentivize the use of cool roofs on both public and residential buildings in all hot-summer Chinese climates. This brings to about 10 the total number of Chinese national, provincial, or municipal standards and green building programs that have incorporated cool-roof credits since the project began in 2011. In November, LBNL received a 2016 R&D 100 Award for the Cool Roof Time Machine. This award recognized the ability of this technology to dramatically accelerate and reduce the cost of prototyping and bringing high-performance cool roofing materials to market.

3. Building Equipment

- ***3.1 Advanced Lighting Controls— Technical Specifications and Functional Requirements for Proof-of-Concept (POC) Lighting Control Systems**:* Since their introduction decades ago, lighting controls have presented a dilemma with regards to energy savings. These systems offer the potential for substantial energy savings. However, it is extremely difficult to quantify the potential savings of a particular lighting controls technology or strategy. For the first time, CERC researchers from LBNL, Lutron Electronics Co., Inc. and China Academy of Building Research (CABR) directly addressed this issue. They developed a method for standards or test procedures to describe how lighting controls systems should measure, estimate, record or report energy use, or attribute energy savings. Researchers accomplished this by installing Lutron's 3rd generation Quantum lighting controls system in the FLEXLAB testing facilities and measuring lighting system performance over a broad range of conditions and controls settings, and then comparing reported luminaire-level energy use to measured energy use. In addition, the lighting controls solutions tested in FLEXLAB were 'driven' by live occupancy data from the CABR building in Beijing. While the test presents the reported-versus-measured results for a specific lighting controls system, the methodologies developed can be applied more broadly to lighting controls systems generally. Ultimately these methods may lead to test procedures and codes for lighting controls systems that ensure accurate and uniform energy use reporting. It is estimated that 40 terawatt hours (TWh) of lighting electricity can be saved annually in the United States at 25% penetration of lighting controls, with electricity savings of 15 TWh/yr in China, for a total of 55 TWh and annual emissions reductions of 38 million metric tonnes of CO_2.

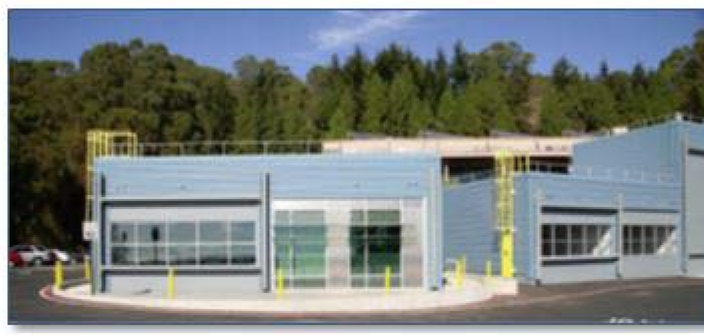

Figure 7: DOE's FLEXLAB Facility at LBNL Utilized for this Experiment

- ***3.2 Natural Ventilation—Tailored Software Package to Improve Design and Optimize Control and Occupant Comfort of Hybrid Ventilation in Commercial Buildings:*** Natural ventilation is a passive cooling technology that holds promise for significant energy savings, while keeping occupants under comfortable conditions. Natural ventilation can reduce energy consumption between 15% and 70% in commercial buildings, depending on the type of building and the climate of the region where it is located. Under CERC-BEE, researchers from the Massachusetts Institute of Technology (MIT), Chongqing University, Tongji University, and Shenzhen Institute of Building Research, developed, improved, and validated CoolVent, a design and analysis tool for naturally ventilated buildings. Research conducted as part of the CERC program increased the capabilities of CoolVent, which makes CoolVent unique in many aspects among other simulation tools for ventilation in buildings. CoolVent can predict the thermal stratification of the air, thus allowing for a more accurate assessment of the comfort conditions in a building, when compared to other tools based on a single, uniform temperature per zone. Furthermore, control strategies for naturally ventilated buildings have been optimized and the results incorporated into CoolVent allowing for analysis of the potential of natural ventilation in different cities in the U.S. for different representative commercial buildings. Due to its multiple capabilities, CoolVent was used as part of the design of the ventilation system and strategy of a commercial building being built in Zhuhai, China. On the basis of this work, CERC industrial partners and academic researchers in the United States and China, modified the design of the façade of this building to improve the performance of its ventilation system. This research is also being utilized to inform the design handbook on natural ventilation being written as part of EIA Annex 62 program. In addition, technical results from the research work have been published in academic journals, including a model to predict thermal stratification in spaces with hybrid natural-mechanical ventilation.

Figure 8: (Left) Nexajoule at 2015 U.S. DOE Solar Decathlon, (right) Tsinghua chiller installed at California Lighting and Technology Center in Davis, CA

- ***3.3 Wet Bulb Evaporative Chiller—Efficient Cooling Strategies for Some U.S. and Chinese Regions:*** Cooling loads constitute approximately 13% of the total demand for the United States; and in the Western United States, the hot dry summers drive cooling loads and peak demand throughout the season. The hot and dry climate creates significant potential to expand the market to incorporate evaporative cooling. Sub wet-bulb evaporative chillers provide one compressor-less solution capable of producing chilled water below the ambient wet-bulb condition which could be used in a radiant or fan coil system. CERC researchers from Western Cooling Efficiency Center (WCEC), University of California, Davis and Tsinghua University, in partnership with Nexajoule L.L.C. and Xinjiang Refreshing Angle Air Environment and Technology Company, completed laboratory testing of two sub wet-bulb evaporative chillers. In laboratory testing, one chiller demonstrated 0.7 – 1.7 tons of cooling capacity at a coefficient of performance (COP) between 8 and 30, while the other chiller demonstrated 3-4 tons of cooling capacity at a COP between 6 and 8. WCEC facilitated demonstration of the Nexajoule chiller at the 2015 U.S. DOE Solar Decathlon and integrated the Tsinghua chiller into an office building radiant system located at UC Davis. The Tsinghua chiller was installed and field tested in summer of 2016 with funding from Pacific Gas and Electric (results are currently being analyzed). Through our corporate affiliate program, WCEC introduced the proprietor of the Nexajoule technology to an evaporative cooling manufacturer who is currently pursuing licensing of the technology and building chillers for two additional demonstration projects funded by the California Energy Commission. In the first demonstration project, the Nexajoule chiller will be used to provide cooling for two residential homes in combination with nighttime ventilation cooling. In the second demonstration project, the Nexajoule chiller will be used to provide chilled water for a conduction cooling system used to cool dairy cows in California's central valley.

4. Renewable Energy Utilization / Distributed Generation

4.1 Ground Source Heat Pump—Improved Energy Efficiency and Cost of Ground Source Heat Pumps; Reducing its System Energy Use by up to 30%: Ground Source Heat Pump (GSHP) is a proven technology that utilizes the clean and renewable geothermal energy, as well as the massive thermal storage capacity of the ground, to provide space conditioning and water heating for both residential and commercial buildings. It has higher energy efficiency than conventional space conditioning and water heating systems. It is estimated that 0.6 Quad Btu primary energy consumption will be reduced each year if GSHP gets 10% market share in the U.S. More significant benefits from GSHP applications are expected in China given the huge building stocks and the severe air pollution there. However, the current market share of GSHP in both China and the U.S. is just around 1%. While high initial cost is the primary barrier preventing wider adoption of GSHP technology in the U.S., it is the lack of standards governing quality of equipment, design, installation, and operation of GSHP systems that shallows the sustainable growth of GSHP applications in China.

Figure 10: Major Equipment of the Flexible Research Facility for DGSHP Systems

The CERC research team, comprised of ORNL, ClimateMaster, Tongji University, Tianjin University, Chongqing University, and China Academy of Building Research (CABR), have made significant progress in reducing the initial cost and further improving the operational efficiency of GSHP systems through low-cost and performance neutral ground heat exchangers (GHXs) and smart controls at component and system levels. CERC researchers have designed new GHXs that require 14-30% less drilling compared with conventional GHX while retaining same performance; created an innovative flow-demand-based pumping control, which has potential to reduce pumping energy of distributed-GSHP (DGSHP) systems by more than 20% (patent pending, Invention Disclosure #: 201403380, DOE S-number: S-138,004); developed a new method and enabling tool for cost effectively monitoring performance and detecting faults of DGSHP systems (Invention Disclosure #: 201403381, DOE S-number: S-138,005); and demonstrated the U.S. style DGSHP system in a highly visible very-low-energy-building of CABR.

Further, as a result of a previous Building Technologies Office (BTO)-funded R&D project concluded in 2013, ClimateMaster successfully launched the new Trilogy™ 45 Q-Mode™ series ground source integrated heat pump (GS-IHP). It is the first GSHP unit certified by the Air Conditioning, Heating, and Refrigeration Institute (AHRI) to exceed a 45 EER performance rating. This product provides space conditioning and 100% water heating, even when space conditioning is not required. This technology development has established a strong foundation for the next-generation of GSHP applications, which integrates the new low-cost performance neural GHXs, the advanced GS-IHP units, the smart pumping control, and the cost-effective virtual sensing based performance monitoring and fault detection system.

In addition to supporting the optimization and field verification needs of this project, the flexible research facility of DGSHP systems built during this project provides a first-of-a-kind facility capable of supporting other valuable research to further improve DGSHP system's energy efficiency over service life and reduce cost (e.g., fault detection and diagnostics, improved control through application of low cost wireless sensors, etc.). With this facility, various emerging technologies can be developed and verified in a low-risk realistic real-building environment. This project will help overcome barriers preventing wider adoption and sustainable growth of GSHP applications in both the U.S. and China.

- ***4.2 Building Integrated Renewable Energy and Micro Grid—Optimized renewable energy technology selection, integration, and operation in real time.*** Micorgrid is an important system to integrate distributed energy systems in buildings. It is also a natural host for renewable energy. It manages distributed energy resources (DER) to be optimally utilized in buildings and communities to meet the load requirement. Optimizing microgrid performance by planning potential distributed energy resources and dispatching energy technologies to operate synergistically is very important for the design and operation of buildings and communities. Under CERC-BEE, a team of researchers from LBNL, Tianjin University, Tongji University, C3 Energy, and Xingye Solar used LBNL's Distributed Energy Resources Customer Adoption Model (DER-CAM) tool to assess the potential for minimizing energy usage and costs in building and district-level microgrid applications in diverse climate zones in the United States and China. Unlike simple technical assessments, DER-CAM is able to gauge the outcome of competition between alternative available technologies for certain building types of certain sizes in specific climate and economic conditions. This open-access web service permits optimization of energy system equipment selection and operation for buildings and small district microgrids. Depending on the data quality, these estimates can be extrapolated to markets or regions. In the United States, this approach has been used to establish a standard set of representative commercial buildings based on U.S. DOE's Reference Buildings. Researchers have developed a preliminary scheme to do real-time optimization and have identified issues of real-time optimization interruption. Application of DER-CAM in the regional studies showed that DER technologies have economic and environmental competitiveness potential, especially for commercial buildings in hot and cold climates of both countries. In the U.S., the average expected energy cost savings in commercial buildings from DER CAM's suggested investments is 17%, while in Chinese buildings it is 12%. The average CO_2 emission reduction potential is about 19% for U.S. commercial buildings. The largest carbon dioxide (CO_2) reduction potential is 40% in U.S. commercial buildings.

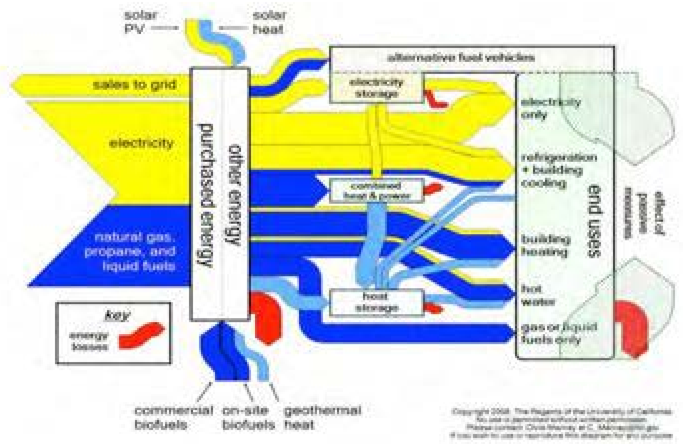

Figure 11: Model of DER-CAM

5. Whole Building

- ***5.1 Energy Systems and Technology for Demonstration Projects—Optimization and evaluation of energy system and operation:*** Researchers at LBNL (U.S.) and Tianjin University (China) have developed a web-based tool to make a simple investment and planning version of DER-CAM for the optimization and control of building equipment and microgrids. The model, called WebOpt, is freely available on the web and has a Chinese language interface. There are over a hundred users of the Chinese version. DER-CAM is currently being extended to optimize overall building control using a cloud tool that optimizes the operation of complex buildings as a software service. This integrated approach has been demonstrated to lower weekly energy costs by up to 30% at a University of New Mexico campus building, which implements the optimized schedules directly in its building energy management system. Best results are achieved in shoulder seasons, when simple control strategies overuse storage.

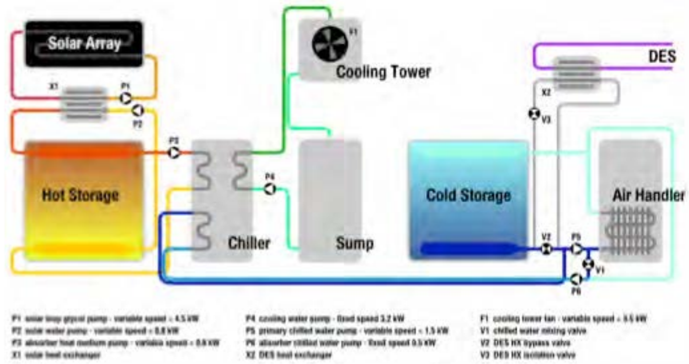

Figure 12: Distributed Energy Resource Diagram in one Building in University of New Mexico

- ***5.2 Promoting Ongoing Commissioning to Ensure Buildings Perform as Expected Through the Life Cycle***: Building Commissioning (Cx) is a systematic process of ensuring that a building performs in accordance with the design intent and the owner's operational needs. It has a significant potential for reducing energy consumption in existing and new buildings. An LBNL study (Mills et al. 2009) showed that building Cx resulted in 16% energy savings in existing buildings and 13% in new construction. A team of CERC researchers from LBNL and MOHURD Center for Science and Technology of Construction (CSTC), in collaboration with California Commissioning Collaborative (CCC), Pacific Gas & Electric (PG&E), Interface Engineering, and Xingye Solar, completed the development of automated commissioning algorithms and validated them through simulation. The team also published the first Chinese commissioning handbook. Overall, project activities promoted the proper use of building Cx and ongoing Cx processes in China and the U.S. to ensure that buildings perform as expected through the life cycle.

Figure 13: China Building Energy Performance Benchmarking Tool Interface

6. Policy, Market Promotion

- ***6.1 Integrated Building Design & Operation—Commercial Building Energy Use Tool:*** Central to the challenge of improving building energy performance is the availability of effective benchmarking tools to motivate market actors to curb energy use. Research shows that an operational benchmark's strength is in providing a practical and equitable assessment of building performance in order to identify energy and financial savings opportunities and make the business case for energy efficiency investments. CERC-BEE researchers from LBNL, ICF International, CABR, and Tsinghua University developed China's first on-line operational benchmarking tool – the China Building Energy Benchmarking Tool. The tool evaluates whole-building, operational energy performance relative to peers and normalizes for factors such as weather and occupancy, and converts site to source energy for a more equitable comparison of performance. The tool helps researchers and decision makers identify Chinese buildings where U.S. technology upgrades are most cost-effective based on anticipated energy savings; identify opportunities to explore the similarities and differences in the U.S. and China's buildings stocks; develop lessons and best practices strategies in building energy management that benefit both the U.S. and China; and deliver processes for buildings in the China marketplace to benchmark their energy use and assess their level of efficiency.
  The tool has been integrated into MOHURD's *Urban-Scale Building Energy Efficiency and Renewable Energy Project: Energy Performance Benchmarking & Disclosure (EPB&D) in Large Public and Commercial Buildings*, which is deploying a national energy performance benchmarking tool. Currently, the China Building Energy Benchmarking Tool is available for offices, hotels, hospitals, and shopping malls at http://115.29.110.113/.

- ***6.2 Developing Energy-Efficient Codes and Standards for Buildings:*** Building codes and standards are one of the most effective measures to ensure energy efficient technologies get widely adopted in buildings, and they can provide expanded markets for U.S. and Chinese products. Developing energy efficient codes and standards is estimated to save 36 tons of CO_2 emissions in the U.S. In China, the commercial building energy standard is estimated to save 249 million tons of coal equivalent (Mtce) of primary energy from 2010 to 2030. Under CERC, researchers from LBNL, Lutron, China Academy of Building Research (CABR), and Xingye Solar worked collaboratively with other U.S. and Chinese partners to develop the next version of commercial building energy standard in China. The team also simulated the new Chinese standard's performance and compared its performance with that of previous codes and ASHRAE 90.1. The joint research shows that the new Chinese standard has achieved energy savings of 62% compared with the 1980's baseline (or 26% compared to its previous 2015 version), and has average simple pay-back period of four years. Furthermore, the team compared the different requirements between the Chinese

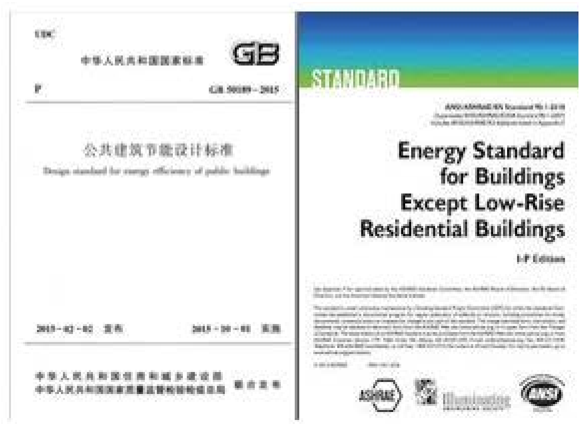

Figure 14: U.S. and Chinese Building Energy Code Analysis

standard and ASHRAE 90.1 and summarized areas where the Chinese standard has different and potential energy-efficiency practices than ASHRAE 90.1, and possibly considered by the future ASHRAE standard upgrade. Lastly, the team identified areas in which the ASHRAE 90.1-2013 requirements exceed those of the 2015 Chinese code and implemented those requirements in EnergyPlus. By facilitating the alignment of Chinese standards to U.S. ASHRAE standards, CERC-BEE is helping accelerate the market uptake of more efficient U.S. and Chinese products.

CERC Phase 2 (2016-2020)[2]

1. Direct Current (DC) Buildings and Smart Grid

- ***Bringing Innovative DC Power Distribution Control Technology to Market*:** CERC researchers from LBNL worked with the IEEE to bring technology from the CERC-DC project into one of the most widely deployed technologies that brings together electricity and information technology: *Ethernet*. The latest update to the standard, IEEE 802.3bt, increases the power that can be carried over a standard Ethernet cable to 90W, and adds additional fields to the data exchanged across the link about that power. Due to our efforts, this is now included as an indicator of the local price of electricity. Local pricing, and standard methods to distribute them, is a core principle of the CERC-DC project plan. The standard is in the last stages of editing and approval, and should be finalized early in 2017.

Figure 15: CERC Research Contributes to Ethernet Standards

- ***Innovative Power Distribution Control Technology:*** CERC researchers from LBNL and the University of South Florida (USF) in the United States worked to create and describe a path forward for DC power distribution to become successful in the market, with an article in the magazine *IEEE Electrification*, entitled "DC Local Power Distribution: Technology, deployment, and pathways to success". The article covers traditional DC power distribution, then presents our proposed new architecture, based on pervasive digital communication and fine-grained management. It also addresses how to deploy the new technology in practice in existing buildings, and how it evolves over time. The article brings together themes from the CERC project in terms of creating new, innovative technology, making clear how it can be beneficial for efficiency and other concerns, and how to practically take it from a laboratory project to wider use in buildings.

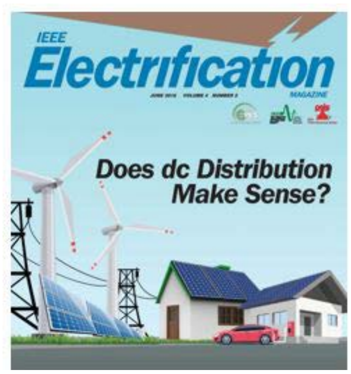

Figure 16: CERC-BEE Research Published in IEEE Electrification Magazine

[2] Research in progress. The section highlights select preliminary outcomes.

2. Indoor Environmental Quality (IEQ)

- ***Developing Next-Generation Air Cleaning Materials with an 80% Increase in CO_2 Capacity Over First Generation Materials.*** In U.S. commercial buildings, outdoor air (OA) ventilation to remove indoor generated pollutants and bioeffluents including CO_2 is a cornerstone of indoor air quality (IAQ) management; and standards are designed to protect IAQ specific minimum ventilation rates. The energy costs to condition outdoor air for ventilation can be substantial and can limit efforts to reduce energy consumption and associated impacts, especially since the highest loads to condition OA occur at time of maximum building occupancy. In many locations in China, the outdoor air is heavily polluted, creating the need to clean the indoor recirculating air or the supplied outdoor air or both, if acceptable IAQ is to be achieved. Researchers from LBNL, alongside industry partners BASF, United Technologies Corporation (UTC), United Technologies Research Center (UTRC), Disney, and Johnson Controls, Inc. are working together to develop and demonstrate technologies that utilize air cleaning, pollutant sensing, and advanced airflow management to achieve acceptable IAQ while also minimizing energy use for heating, ventilation, and air conditioning (HVAC). Advances are being made in air cleaning technologies for formaldehyde, volatile organic compounds (VOCs), and CO_2; integrating air cleaning with ventilation by real-time monitoring using low-cost sensors; and develop simulation tools to aid system design and selection for different building types, climates, and air quality challenges. In the second quarter of 2016, BASF made advancements towards its goal of developing next-generation air cleaning materials and technologies by producing a second generation (Gen2) sorbent. BASF demonstrated that the new sorbent has a capacity of >14 g CO_2 adsorbed per L of sorbent (g/L) and maintains its CO_2 adsorption capacity under humid conditions. This represents a >80% increase in CO_2 capacity over the Gen1 materials, which will enable more flexible and practical designs of CO_2 scrubbing units in HVAC systems to reduce ventilation and related energy consumption.

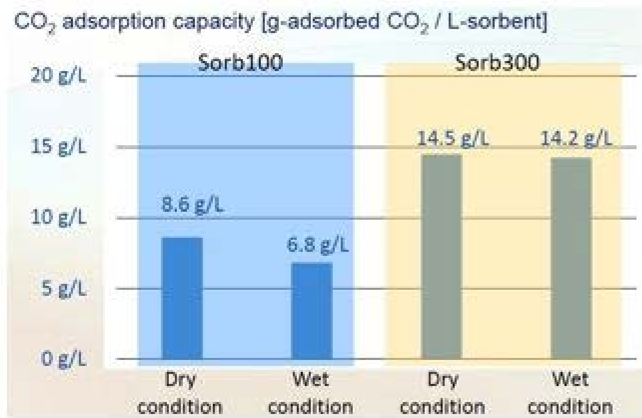

Figure 17: Gen2 Air Clean Materials (right) Compared to Gen1 (left)

3. Markets and Policy Initiative

- ***Drafted the First U.S.-China Joint Intellectual Property (IP) Agreement for an Innovative Open-Source Building Energy Efficiency Auditing Software Tool***. Today, U.S. and Chinese buildings account for close to 40% of total global energy consumption, and this is expected to increase rapidly over the next several decades without further improvements in building energy performance. In recent years, municipal governments globally have determined that building energy performance benchmarking and disclosure laws are effective in encouraging the development of a strong market for building energy efficiency. While important, benchmarking and disclosure laws are only valuable if they inspire action (i.e., retrofits of underperforming buildings), yet consistent and cost-effective approaches to carry out post-benchmark audits at scale are unavailable. Researchers from LBNL, ICF International, and China Academy of Building Research (CABR) are partnering with Johnson Controls Inc. and United Technologies Research Center (UTRC) to fill this gap by developing a free, open-source, public-access on-line software tool (based on Johnson Control's LEAN Energy Analytic Tool and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)'s Inverse Modeling Toolkit) that supports up-front assessment of retrofit opportunities and monitoring and verification (M&V) of energy and cost reductions in buildings. The tool will go a step beyond traditional benchmarking to not only assess energy performance, but to identify specific equipment and systems that are underperforming and quantify the energy and cost savings associated with upgrades. In the second quarter of 2016, the research consortia made advancements toward its software tool launch by drafting the first U.S.-China joint intellectual property (IP) agreement, which sets forth the conditions and terms for the protection of background IP and for the allocation of Project IP, ensuring that IP is protected appropriately both in the United States and Chinese law. This is the first draft U.S.-China joint IP agreement under the CERC-BEE program and will set a precedent for future U.S.-China joint IP agreements under CERC.

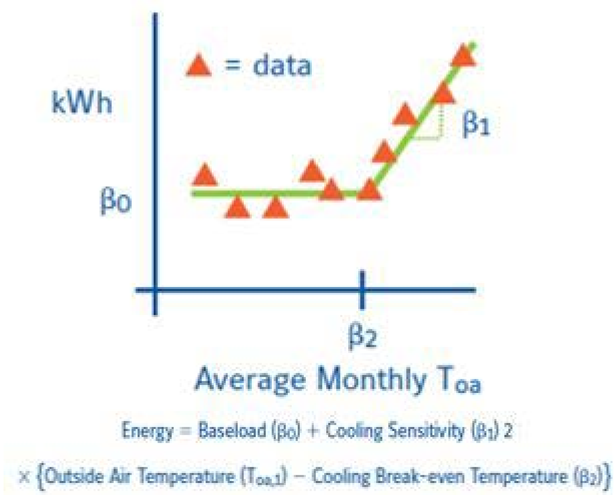

Figure 18: Inverse Model for Open-Source Audit Tool

4. Integrated Design, Construction, and Industrialized Buildings

- ***Next-Generation Precast Insulated Wall Panels for New Buildings.*** Researchers from Oak Ridge National Laboratory (ORNL), University of Tennessee, and Institute for Advanced Composites Manufacturing Innovation are collaborating with the Precast/Prestressed Concrete Institute to develop the next generation of architectural precast (off-site) insulated wall panels. Off-site construction typically yields better performing building envelopes than those that are assembled on-site. The goal of the project is to implement the latest advances in material sciences and manufacturing to develop wall panels that have 50% higher thermal performance and are 50% lighter without increasing the cost of the panel. Recent achievements include the manufacture of a complex prototype mold for concrete. The prototype was about 30% faster to manufacture through 3D printing and CNC finishing than through the typical manual assembly process, while generating impressive finishing quality.

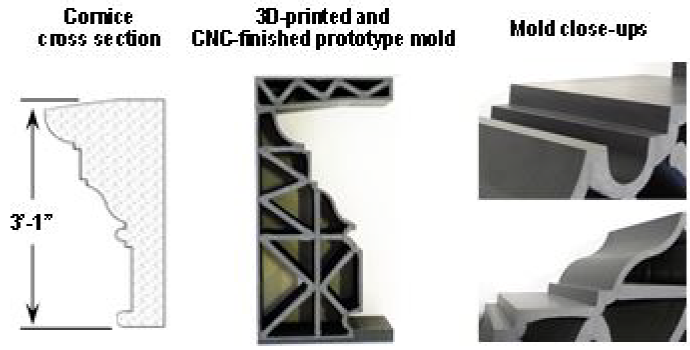

Figure 19: Next-Generation Precast Wall Panels

Figure 20: Retrofit Case Study Buildings

- ***Energy-Saving Case Studies of Envelope Retrofits for Existing Buildings.*** ORNL is working with Dow Chemical, 3M, and Saint-Gobain to generate case studies of envelope retrofits because existing structures consume most of the energy that is attributed to the building sector. The objective of the project is to give building owners confidence on the energy savings that they can expect from envelope retrofits. To achieve this, data will be gathered from actual buildings on their performance before and after their envelopes are retrofitted. These are needed because most of the available information is not sufficient for owners to make educated decisions given that the data are either anecdotal or primarily based on simulation models. Two potential retrofit buildings have been identified: the Dundee Theater in Omaha, Nebraska, and the Chase Mills building in Watertown, MA. Both retrofits are scheduled to occur in the spring of 2017.

The article "Building Envelope Advancement Under the U.S.-China Clean Energy Research Center for Building Energy Efficiency" was published in the August issue of the journal *Interface*. The article aimed to give the general public an overview of how ORNL is collaborating with various institutions and industries to improve the envelope of new and existing commercial buildings.

5. Integrated Controls, Commissioning, and Data Mining

- ***Developing a Software Platform to Aid in Rapidly Deploying Model Predictive Controls (MPC) in Buildings for Superior Energy Performance and Resiliency***. Within the last decade, concerns over energy costs and climate resiliency have brought about new requirements for building systems. These include reducing energy costs, energy usage, and peak demand, as well as facilitating building-grid integration, district-energy system optimization, and occupant connectivity. Many of these requirements depend upon a building's ability to consider time-based incentives and direct the operation of multiple subsystems towards a common objective. Current proportional–integral–derivative (PID) and schedule-based control systems are not capable of fulfilling these needs, while an advanced control technique called Model Predictive Control (MPC) is. However, despite past research showcasing the capabilities of MPC to meet these new requirements, and the critical role buildings play in our energy systems and daily lives, MPC has not achieved widespread use in the building industry. The main barrier is high engineering setup costs and expertise, and subsequent lack of demonstration of a single platform across projects. Researchers from LBNL, alongside industry partners Johnson Controls Inc., Disney, United Technologies Corporation (UTC), Lutron, and Lendlease, are working together to develop, demonstrate, and distribute a software platform to aid in rapidly deploying MPC in buildings. The platform emphasizes the use of adaptive building and occupant models, which can be learned from performance data over time, and the automation of model learning and optimization problem formulation and solving. Both these features contribute to reducing setup time and expertise. In addition, the use of open-source software standards and extensible architecture allow for adoption and expansion by industry and researchers without compromising code longevity. LBNL has recently completed a preliminary prototype of the MPC software, with demonstration of key features on simple models. This included estimation of building envelope model parameters based on simulated data and optimization of HVAC control, each with automatic formulation and solving of the respective problems. In addition, an adaptive occupant model to predict the likelihood of occupants opening windows was implemented in modelica and tested in a building simulation.

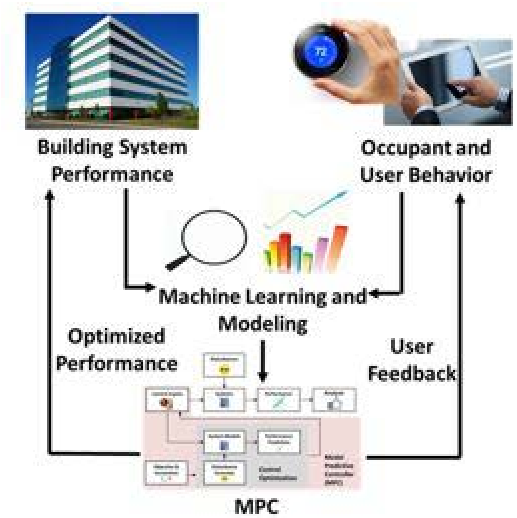

Figure 21: Framework for MPC